NISTIR 6242

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## Book of Abstracts
## November 2-5, 1998

Kellie Ann Beall, Editor

Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

**United States Department of Commerce**
**Technology Administration**
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**U.S. Department of Commerce**
William M. Daley, *Secretary*
**Technology Administration**
Gary Bachula, *Acting Under Secretary for Technology*
National Institute of Standards and Technology
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# AN EXPERIMENTAL AND THEORETICAL INVESTIGATION ON FLAME EXTINCTION BY SODIUM BICARBONATE PARTICLES

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## Introduction

A steady, laminar, nonpremixed flame, established within the mixing layer of a counterflow of methane and air, is used here to quantify the rate-controlling physical, thermal and chemical contributions of sodium bicarbonate particles on flame extinction. The basic understanding obtained from this effort is expected to benefit development of enhanced condensed-phase fire suppressants. A brief description of the present experimental and theoretical/computational efforts and recent results are given below.

## Experiments

An enclosed counterflow burner, designed with Pyrex coannular nozzles with nitrogen co-flow on both fuel and air side is used in the present experimental study. The particles are introduced with the air stream. The Pyrex tubes allow for ease of fabrication, and more importantly, for viewing of particle motion through the tubes. The fuel used is methane (99.99% pure, BOC) and air is supplied from an oil free compressor with moisture removed by passing through a drier. Once ignited, very stable diffusion flames with and without particles can be established in the enclosed burner for extended periods of time (Krauss et al. 1998).

Considerable attention has been devoted to the development of a particle seeder that can deliver steady feed rates of particles of various sizes (i.e. from 0 to 100 $\mu$m). The design selected is a positive feed auger system consisting of a Teflon screw in a high-precision stainless steel tube where the screw is driven by speed-locked variable speed motor, as illustrated in Fig. 1. The seeder is vibrated by a pneumatic system to assist the particle flow, but the particle feed rate is primarily controlled by the motor rpm. Part of the total air flow is diverted through the particle seeder and is then mixed with the remaining air prior to exiting through the air nozzle. The particle feed rate is continuously monitored using a Mie scattering detection system located at the exit of the seeder air. The actual mass fraction of the particles in the air stream is determined by calibrating the recorded scattering signal by a separate gravimetric analysis, either before or after each experiment.

In counterflow flame experiments, the extinction flow strain rate (which is related to the axial velocity gradient along the axis of symmetry) is typically reported based on the (a) global strain rate formula derived by Seshadri and Williams (1978) under a set of simplifying assumptions or (b) local velocity measurements along the axis of symmetry using LDV. The former requires information regarding the nozzle exit velocities of the fuel and air streams and the nozzle separation distance. In this work, most of the reported extinction strain rates are based on the global formula, but for comparison the locally measured flow strain rate obtained with a LDV system operating forward scattering mode is used.

## Numerical Calculations

Based on a hybrid Eulerian-Lagrangian formulation for the gas and the condensed phase, a numerical model was recently developed to describe the interaction of fine-water droplets with counterflow nonpremixed flames (Lentati and Chelliah, 1998). This model is extended here to predict the flame extinction phenomena by sodium bicarbonate particles and the preliminary results with a global particle decomposition model is presented. Such theoretical approaches, once validated, can provide detailed information about the rate controlling physical, thermal and chemical effects of sodium bicarbonate particles.

## Results and Discussion

Previous counterflow experiments with fine sodium bicarbonate particles have indicated a nonmonotonic variation in their effectiveness (Hamins et al.1994). The present results, however, do not indicate such non-intuitive trends as the particle size is decreased. Figure 2 shows a monotonic variation of sodium bicarbonate mass fraction in air plotted as a function of the extinction strain, for three different particle size groups. As the particle size decreases below 20 $\mu$m, the particle feed rate becomes rather unsteady and the quantitative values of measured flame extinction strain rate can be unreliable. However, qualitatively, the experimental results for particles below 20 $\mu$m indicate a similar monotonic increase in the effectiveness with decreasing particle size, which contradicts the previous data reported by Hamins et al. (1994).

In numerical predictions of flame extinction by sodium bicarbonate particles, a global model for particle decomposition of the form $2NaHCO_3 \rightarrow 2NaOH + 2CO_2$ is employed here, with the associated physical, thermal and chemical effects. Although such a global model can be fine tuned to a very narrow range of conditions, eg. for a narrow particle size range, it should be cautioned that extension of such models to a wider range of conditions may lead to physically unrealistic results. For the homogeneous chemistry associated with NaOH, a detailed reaction model involving 6 species in 20 elementary reactions is used here, in conjunction with the detailed chemistry model for methane oxidation (Lentati and Chelliah, 1998). Figure 3 shows a plot of the predicted variation of peak flame temperature as a function of flow strain rate (up to extinction), for selected particle sizes. The results clearly indicate that as the particle size is decreased, the effect on flame extinction strain rate increases rapidly. These results are qualitatively consistent with experiments, but more comprehensive modelling of the particle heating, heterogeneous and homogeneous decomposition mechanisms must be addressed before any quantitative comparisons are made. Such efforts are currently underway and are expected to provide valuable information in future development of enhanced condensed-phase fire suppressants.

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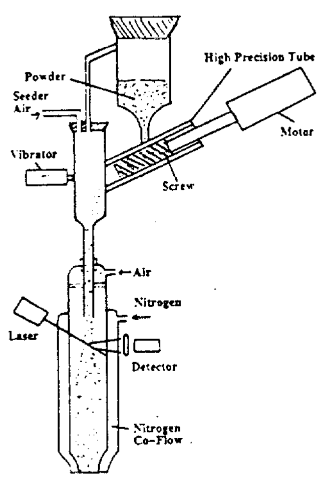


Figure 1: A schematic of the particle seeder.

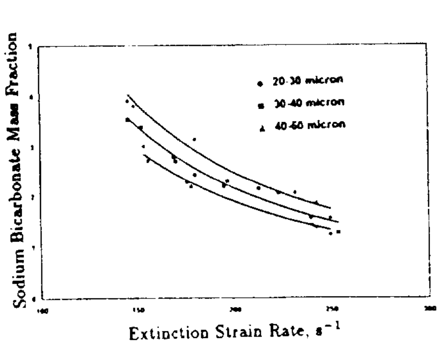


Figure 2: Measured particle mass fraction vs. global extinction strain rate, for three different size groups.

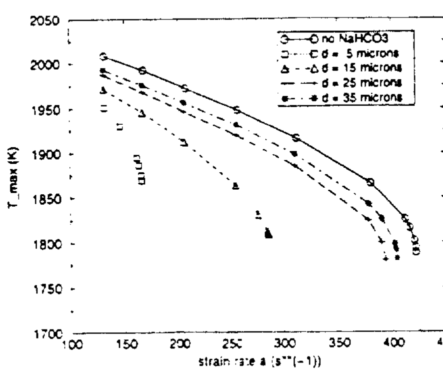


Figure 3: Predicted variation of peak flame temperature as a function of strain rate, for various particle sizes.